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A TIME-OF-FLIGHT DETECTOR FOR CDF

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A Time-of-Flight detector (TOF), with a technique based on plastic scintillators and fine-mesh photomultipliers, has been added to the CDF-II experiment. The main physics motivation is to improve neutral B meson flavor determination by $K^{\pm}$ identification. The expected time resolution is 100 ps, which provides at least two standard deviations separation between $K^{\pm}$ and $\pi^{\pm}$ for momenta $p < 1.6$ GeV/c and better than 1.2 standard deviations separation over all momenta when combining TOF identification with dE/dx identification using the new drift chamber.

1. Introduction

After the Run I data taking period from 1992 to 1996, the CDF experiment is undergoing a major upgrade[1]. A time-of-flight (TOF) system is being added to the detector to improve the particle identification capability[2]. The chosen TOF technique is based on plastic scintillators and photomultipliers. The primary purpose of the TOF is to provide charged kaon identification to determine the b flavor of B hadrons.

For a given flight distance, and with an expected time resolution of 100 ps, the average statistical separation between $K^{\pm}$ and $\pi^{\pm}$ for momenta $p < 1.6$ GeV/c is better than two standard deviations. When TOF identification is complemented with dE/dx identification from the central drift chamber, at least 1.2 standard deviations separation is expected to be achieved for all momenta.

2. The TOF system

2.1. *The Scintillator Bars*

The TOF detector consists of 216 bars of Bicron BC-408 scintillator, which was selected for its long attenuation length ($\Lambda_{\text{eff}}\sim$250 cm) and fast rise time ($\sim$ 0.9 ns). The bars are 279 cm long and 4 cm by 4 cm in cross-section. They are installed at a radius of $\sim$138 cm from the beam in the 4.7 cm of radial space between the main drift chamber and the cryostat of the superconducting solenoid. The pseudo-rapidity ($\eta = -ln(tan(\theta/2))$, with θ the polar angle) coverage of the system is roughly $|\eta| < 1$.

To facilitate the handling of the bars, they are grouped in a total of 72 triplets. Each bar is wrapped in white paper and a hollow aluminum block is attached to both ends to hold the photomultiplier tubes. To increase light tightness, the outermost bars of each triplet are also wrapped in black paper, finally the triplet is wrapped again with strong black light-tight foil.

2.2. *The Photomultipliers*

A Hamamatsu R7761, 19-stage, fine mesh photomultiplier (PMT) tube is attached to each end of the scintillator bars for a total of 432 PMTs in the system. These tubes can operate in the 1.4 T magnetic field produced by the CDF solenoid, but with reduced gain. An initial analysis of the performance of the tubes indicated an intrinsic timing resolution better than 100 ps and an average gain reduction factor of 500 in the 1.4 T CDF magnetic field.

The PMT is inserted into an aluminum housing that is attached to the end of the scintillator bars. The assembly consist of a silicone pad, a parabolic light concentrator (Winston cone), the PMT, a high voltage base, a preamplifier, and a cap that holds a board for electrical connections and a spring. To allow a possible future replacement of the PMTs, they are not glued to the scintillator bars. The spring holds the PMT assembly against the scintillator bar, sandwiching the silicone pad between the cone and the bar, avoiding air gaps and suppressing light reflection. To improve the light collection, the Winston cone is attached with optical cement to the PMT. The Winston cone focuses the light from the maximal diameter of 1.5 inches onto the sensitive area of the photocathode.

2.3. *The Electronics*

A custom designed high voltage base is attached to the PMTs. A differential signal is formed from the anode and the last dynode stage. A minimum ionizing particle passing through 4 cm of scintillator at the face of the phototube yields a differential signal of about 100 mV when the anode and dynode are terminated into 50 Ω and the PMT high voltage is set to the value corresponding to the expected operating gain. A preamplifier drives the differential signal over 10 m of twisted pair cable to the VME-based front-end electronics. The preamplifier has a nonlinear response: for minimum ionizing particles the gain is about ten; for highly ionizing particles the gain falls to two. At the VME crates the signal follows two paths, one for the timing measurement, and the second for a charge measurement. In the first path, the signal is fed into a leading edge discriminator and the output serves as the start signal for the Time to Amplitude Conversion (TAC) circuit. The TAC is stopped by a common stop signal produced by a precision clock with a specified jitter of less than 25 ps. In the second path a gated integration of the charge of the pulse is used to correct the time measurement for pulse height dependence.

Both the output of the TAC and of the gated integrater are fed into a CDF calorimeter ADC and Memory board (ADMEM)[1]. The calorimeter system uses a daughter board (the CAFE card) with a 10-bit ADC. These same CAFE cards are used for the charge measurement in the TOF system. The output of the TAC goes to a specially designed daughter-board (deCAF) that is more simple than the CAFE card, but with a 12-bit ADC; more bits are required to achieve the desired timing resolution. Using the ADMEM boards allows straightforward integration of the TOF front-end electronics into the CDF data acquisition system.

3. Prototype TOF and conclusions

A TOF prototype system with 20 bars 130 cm long was installed inside the CDF solenoid at the end of Run I[3]. The scintillator material was also Bicron BC-408, and the PMTs used were 16-stages fine-mesh R5946.

Certain problems with the prototype system, in particular broken joints in the coupling between the PMT and the scintillator, and very low amplitude signals from the 16-stage PMTs within the 1.4 T magnetic field, led to changes reflected in the current system. The PMTs are not glued to the bar, and we use 19-stage PMTs instead of 16-stage PMTs.

Using cosmic ray muons, a resolution of about 110 ps has been obtained with 16-stage PMTs on a one bar test stand. With the same experimental layout, 19-stage PMTs, similar to the ones used for the TOF, showed a comparable timing performance[3].

We can conclude that based on the latest test results, the improved TOF design, and the recent PMT timing test that the specified 100 ps should be achieved.

1. The CDF II Collaboration, R. Blair *et al.*, *The CDF II Detector Technical Design Report*, FERMILAB-PUB-96/390-E.
2. The CDF-II Coll., *Proposal for enhancement of the CDF-II Detector: an Inner Silicon Layer and Time of Flight Detector (P-909)*, http://www-cdf.fnal.gov/upgrades/btb.proposal.ps.
   Update to proposal P-909:
   Physics Performance of the CDF-II with an Inner Silicon Layer and a Time of Flight Detector, http://www-cdf.fnal.gov/upgrades/*btb_update_jan99.ps*
3. F.Ukegawa et al.,*Nucl. Instr. and Meth.*, A439 (2000), 65-79.